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THE EFFECT OF MODIFIED BAFFLES AND AUXILIARY-COOLING DUCTS ON THE COOLING OF A DOUBLE-ROW RADIAL ENGINE

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Army Air Forces, Air Technical Service Command

THE EFFECT OF MODIFIED BAFFLES AND AUXILIARY-COOLING DUCTS ON THE COOLING OF A DOUBLE-ROW RADIAL ENGINE

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SUMMARY

Tests were conducted in the Cleveland altitude wind tunnel to determine the cooling effect of modified baffles and auxiliary-cooling ducts on the rear-row cylinders of a double-row radial engine in the power-plant installation of a four-engine heavy bomber.

When the standard baffles were replaced by modified baffles, the average temperatures of the exhaust-valve seats of the rear-row cylinders were reduced 30° to 50° F for various operating conditions. The modified baffles had little effect on the valve-guide temperatures. The auxiliary-cooling ducts reduced the temperatures of the exhaust-valve seats 40° to 60° F and the temperatures of the rear spark-plug gaskets 40° to 70° F over the standard installation for various operating conditions.

INTRODUCTION

Exhaust-valve and valve-guide failures on a double-row radial engine in a four-engine heavy bomber have been attributed to excessive valve-seat temperature. (See reference 1.) Excessive temperatures at the valve seat accompanied by large temperature gradients result in warping of the seat. Because of this warping, combustion gases leak by the valve in its closed position and impinge on the exhaust-valve-guide boss with the result that the valve boss and guide are gradually burned away.

The temperatures of the rear-row exhaust-valve seats averaged approximately 40° F higher than the temperatures of the front-row seats. Measurements of the temperature distribution

about these rear-row seats showed that the rear of the seat was a maximum of 181° F hotter than the front of the seat. The high temperatures and the large temperature gradients at the rear-row exhaust-valve seats were attributed to inadequate baffling, which did not furnish a direct supply of cooling air to the fins under the exhaust port. This problem was not encountered on the front-row cylinders inasmuch as these fins faced directly into the air stream.

The test results from unpublished data show that the temperature and the temperature gradient are reduced if the hot area of the valve seat is cooled by an external air blast. Modified baffles and auxiliary-cooling ducts designed to supply a cooling-air blast to the hot area of the rear-row exhaust-valve seat were therefore investigated and the results are presented herein. Other NACA baffles designed for the same purpose are discussed in references 2 and 3. The baffles investigated were not intended to correct for the excessive temperatures of the exhaust-valve guides known to exist on the front-row cylinders. The tests were conducted in the Cleveland altitude wind tunnel at the request of the Army Air Forces, Air Technical Service Command, as a part of an extensive investigation to improve the cooling and reduce the cooling drag of the bomber power-plant installation.

DESCRIPTION OF APPARATUS

A photograph of the modified right inboard nacelle in the altitude wind tunnel is shown in figure 1. The nacelle included a cowling with a 43-inch-diameter inlet, a standard cowl afterbody, and production long cowl flaps. The power unit included an 18-cylinder double-row radial engine equipped with a single-stage gear-driven supercharger, two turbosuperchargers, and a four-bladed propeller. The propeller was 16 feet and 7 inches in diameter and rotated at 0.35 engine speed. The engine had a normal-cruising rating of 1350 brake horsepower at an engine speed of 2100 rpm and a normal rating of 2000 brake horsepower at 2400 rpm.

Baffles

The modified baffles tested were provided by the Wright Aeronautical Corporation and were similar in design to the NACA ducted baffles. The assembly of the modified baffles on a rear-row cylinder is shown in figure 2. The baffle assembly consisted of a head deflector, a spark-plug air scoop, and a two-piece barrel baffle. The principal modification to the standard baffles was the addition of an air duct attached to the rear-row left barrel baffle, which

conducted cooling air from the front of the cylinder to the hot area beneath the exhaust-valve port in the rear of the cylinder. (See fig. 2(a).) A comparison of the standard and the modified left barrel baffles is shown in figures 3, 4, and 5. The duct of the modified baffle has an inlet area of 3.0 square inches, an outlet area of 3.7 square inches, and a minimum cross-sectional area of 1.8 square inches (fig. 3(b)). The minimum area in the duct passage occurred where the duct passed between the intake push-rod housing and the cylinder. (See fig. 2(c).)

The modified baffle design included several other changes of less importance. The upper part of the left rear-barrel baffle was extended farther to the rear of the cylinder than the original baffle. (See fig. 3(b).) The right rear-barrel baffle was cut back, as indicated in figure 4, to avoid blocking the outlet for the blast air leaving the fins under the exhaust port. Rubber seals were installed on the head deflector and the spark-plug scoop to reduce the gap between them. (See fig. 2(a).) The top section of the left barrel baffle of a front-row cylinder was cut back approximately $2\frac{1}{4}$ inches. (See fig. 5.)

The modified baffles were installed on all of the rear-row cylinders except cylinders 9 and 13, which were fitted with standard war-engine baffles. Installation of the modified baffles on these cylinders would have necessitated a slight modification to the external oil supply and the return lines to the front pump.

Auxiliary-Cooling Ducts

An auxiliary-cooling duct (fig. 6) was designed and tested in order to investigate the effect of a larger mass of cooling air on the hot area of the rear-row cylinders than provided by the modified baffles. The duct was made in two sections joined by a neoprene sleeve to facilitate installation. (See fig. 7(a).) The front half of the duct was made integral with the head deflector of a front-row cylinder. The rear half was fastened to the rear studs on adjacent rocker boxes. The minimum area of the duct, the inlet, was 10 square inches; the maximum area, the outlet, was 13.25 square inches. (See fig. 7(b).) The auxiliary-cooling ducts were installed on cylinders 1, 3, and 5, which were equipped with standard war-engine baffles for these tests. Auxiliary-cooling ducts were omitted from the remaining cylinders to avoid complicating the installation.

Instrumentation

Rear spark-plug-gasket, imbedded rear spark-plug-boss, and cylinder-base thermocouples were installed on all cylinders. Exhaust-valve-seat temperatures were measured on 13 cylinders and exhaust-valve-guide temperatures on 7 cylinders. The thermocouples on the rear spark-plug gasket, the rear spark-plug boss, and the exhaust-valve seat and guide were located as shown in figure 8. The cylinder-base thermocouple was peened into the rear of the cylinder-barrel flange. Cooling-air temperatures were obtained with two shielded thermocouples located in front of cylinders 6 and 14. The carburetor-air temperature was measured at the upper deck of the carburetor. All temperatures were recorded on self-balancing potentiometers.

The fuel used for the tests conformed to specification AN-F-28, grade 100/130. Fuel flow was measured by a calibrated rotameter. Brake horsepower was determined by means of a torquemeter furnished with the engine and the thrust of the installation was recorded by the wind-tunnel scales.

TESTS AND METHODS

Comparative tests were made with the standard baffles, the modified baffles, and the auxiliary-cooling ducts. All tests were conducted at a pressure altitude of 15,000 feet and an indicated airspeed of 190 miles per hour. The tunnel-air temperature was approximately 15° F at normal-cruising power and 25° F at rated power. All tests were made at the same engine conditions and cowl-flap deflection to permit direct comparisons. Data were recorded only after the engine temperatures had stabilized.

The tests were conducted for a range of cowl-flap deflections at normal-cruising power for -2° and 1° angles of attack and at rated power for -2° angle of attack. The tests at normal-cruising power were made at full throttle and automatic-lean mixture setting at a fuel flow of 650 pounds per hour, whereas the tests at rated power were made in automatic-rich setting at a fuel flow of 1420 pounds per hour. The fixed top cowl flaps were set at $2\frac{1}{2}$-inch gap throughout the tests.

RESULTS AND DISCUSSION

The modified baffles and the auxiliary-cooling ducts have been evaluated by comparing the resulting cylinder-head temperatures with the temperatures obtained at the same operating conditions with the standard baffles installed. Direct comparisons were made by correcting the temperature data to mean reference values of the ambient cowl-inlet air and carburetor-deck temperatures. A correction of 1° F was applied for each 1° F variation in cowl-inlet air temperature from the reference temperature and a correction of 0.3° F was applied for each 1° F variation in carburetor-deck temperature.

The values of net thrust given are the measurements taken on the wind-tunnel thrust scale and are equal to the difference between the propeller thrust and the drag of the installation. The angle of attack is defined as the inclination of the thrust axis to the horizontal. No corrections have been applied for wind-tunnel effects. The relation of cowl-flap deflection to trailing-edge gap is shown in figure 9.

Modified Baffles

A comparison of rear spark-plug-gasket and exhaust-valve-seat temperatures for standard and modified baffles is shown in figure 10 for several operating conditions. The values given are the averages of the temperatures of the seven rear-row cylinders on which modified baffles were installed. The modified baffles reduced the average temperatures of the rear spark-plug gasket and the exhaust-valve seat approximately 30° F for the entire range of cowl-flap deflections investigated at a -2° angle of attack and 1350 brake horsepower. At rated power (2000 rpm), the average temperatures of the spark-plug gasket were reduced approximately 25° F and the temperatures of the exhaust-valve seat about 32° F. The temperatures obtained for the individual engine cylinders with standard and modified baffles for various operating conditions are compared in figure 11. The temperature reductions of the hottest cylinder head were generally greater than the average reductions. The following table shows the values obtained at a cowl-flap gap of 1.58 inches:

Angle of attack (deg)	Brake horse-power	Temperature reduction with modified baffles			
		Rear spark-plug gasket		Exhaust-valve seat	
		Hottest (°F)	Average (°F)	Hottest (°F)	Average (°F)
-2	1350	28	30	39	32
1	1350	46	40	61	51
-2	2000	40	28	42	31

The foregoing table and figures 10(a) and (c) also show that the modified baffles reduced the cylinder temperatures more at an angle of attack of 1° than at -2°. The effects of angle of attack on cylinder-head temperatures for the standard and the modified baffle installations is further illustrated in figure 12. The cylinder-head temperatures obtained with the standard baffles (fig. 12(a)) increased with an increase in angle of attack, whereas the temperatures obtained with the modified baffles (fig. 12(b)) decreased slightly with an increased angle of attack. This improvement in cylinder-head cooling with increased angle of attack is advantageous in overcoming the cooling difficulties usually experienced with conventional cowlings.

Approximately the same temperature reductions were obtained at the rear spark-plug-boss as at the rear spark-plug gasket when the modified baffles were installed. (See fig. 13.) These data indicate that the air blast from the baffle duct cooled the metal of the cylinder head as well as that of the spark-plug gasket.

In contrast to the marked improvement in cooling at the rear spark-plug gasket and the exhaust-valve seat, the valve-guide temperatures for both the front and the rear-row cylinders were not appreciably affected by the modified baffles. (See fig. 14.) The temperature values given for the front-row valve guides are the averages of the temperatures measured at only two cylinders and consequently may not be representative of the guide temperatures on the other seven front-row cylinders. Cylinder-base temperatures were unaffected by the installation of the modified baffles.

The gains effected by the modified baffles have thus far been given in terms of temperature reductions. The gains in thrust that can be realized for equal engine cooling are also of interest. A comparison at a pressure altitude of 15,000 feet of the variation of net thrust with the hottest spark-plug-gasket and exhaust-valve-seat temperatures, corrected to an Army summer day, for the standard and the modified baffle installations is shown in figure 15.

The difference in drag of the two installations for any specified operating temperature can be readily obtained from this figure. Because of the relatively small cowl-flap deflections required for cooling at an altitude of 15,000 feet and an indicated airspeed of 190 miles per hour, the difference in drag of the two installations is not very great when compared at a rear spark-plug-gasket temperature of 450° F. If calculated for higher altitudes at which larger cowl-flap deflections are required, however, the difference in drag would rapidly increase.

Auxiliary-Cooling Ducts

A comparison of the temperatures obtained with the auxiliary-cooling ducts and with the standard and the modified baffles is shown in figure 16 for various operating conditions. The temperature data presented in these figures are the averages of cylinders 1 and 5. Inasmuch as the cooling duct on cylinder 3 became loose during the test, data on this cylinder are not included. At a -2° angle of attack, the temperatures of the rear spark-plug gasket were reduced 25° F more with the auxiliary-cooling ducts than with the modified baffles; at a 1° angle of attack, however, the reductions were approximately equal. The temperatures of the exhaust-valve seat were about the same for the two modifications at a -2° angle of attack, but at a 1° angle of attack the temperatures were reduced approximately 20° F more with the auxiliary-cooling ducts than with the modified baffles. The drag of the auxiliary-cooling-duct installation was not measured.

Although greater temperature reductions were obtained with the auxiliary-cooling ducts, the modified baffles were less difficult to install and permitted easier servicing of the engine.

SUMMARY OF RESULTS

Results from tests of standard and modified baffles and auxiliary-cooling ducts on a double-row radial engine in a four-engine heavy bomber power-plant installation showed that:

1. The modified baffles appreciably reduced the temperatures of the rear spark-plug gaskets, the rear spark-plug bosses, and the exhaust-valve seats of the rear-row cylinders.

2. The modified baffles did not appreciably affect the temperatures of the exhaust-valve guide.

3. When compared on the basis of equal cooling of the rear spark-plug gaskets and the exhaust-valve seats at conditions requiring large cowl-flap deflections, the drag of the installation equipped with modified baffles was considerably lower than with standard baffles.

4. With the standard baffles, temperatures of the rear spark-plug gasket and the exhaust-valve seat increased with an increase in angle of attack, whereas with the modified baffles these temperatures decreased slightly with an increase in angle of attack.

5. The installation of auxiliary-cooling ducts provided a large mass of cooling air at the rear of the rear-row cylinders and resulted in equivalent or, in some cases, improved cooling over that obtained with the modified baffles; however, the ducts caused a greater installation problem and made servicing of the engine more difficult than the modified baffles.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio, March 20, 1945.

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2. Silverstein, Abe, and Kinghorn, George F.: Improved Baffle Designs for Air-Cooled Engine Cylinders. NACA ARR No. 3H16, 1943.

3. Sipko, Michael A., Cotton, Charles B., and Lusk, James B.: Effect of Ducted Head Baffles on Rear-Row Cylinder Temperatures of Wright R-3350 Engine. NACA MR No. E5C03, Army Air Forces, March 3, 1945. (Available as NACA TN No. 1053, 1946.)

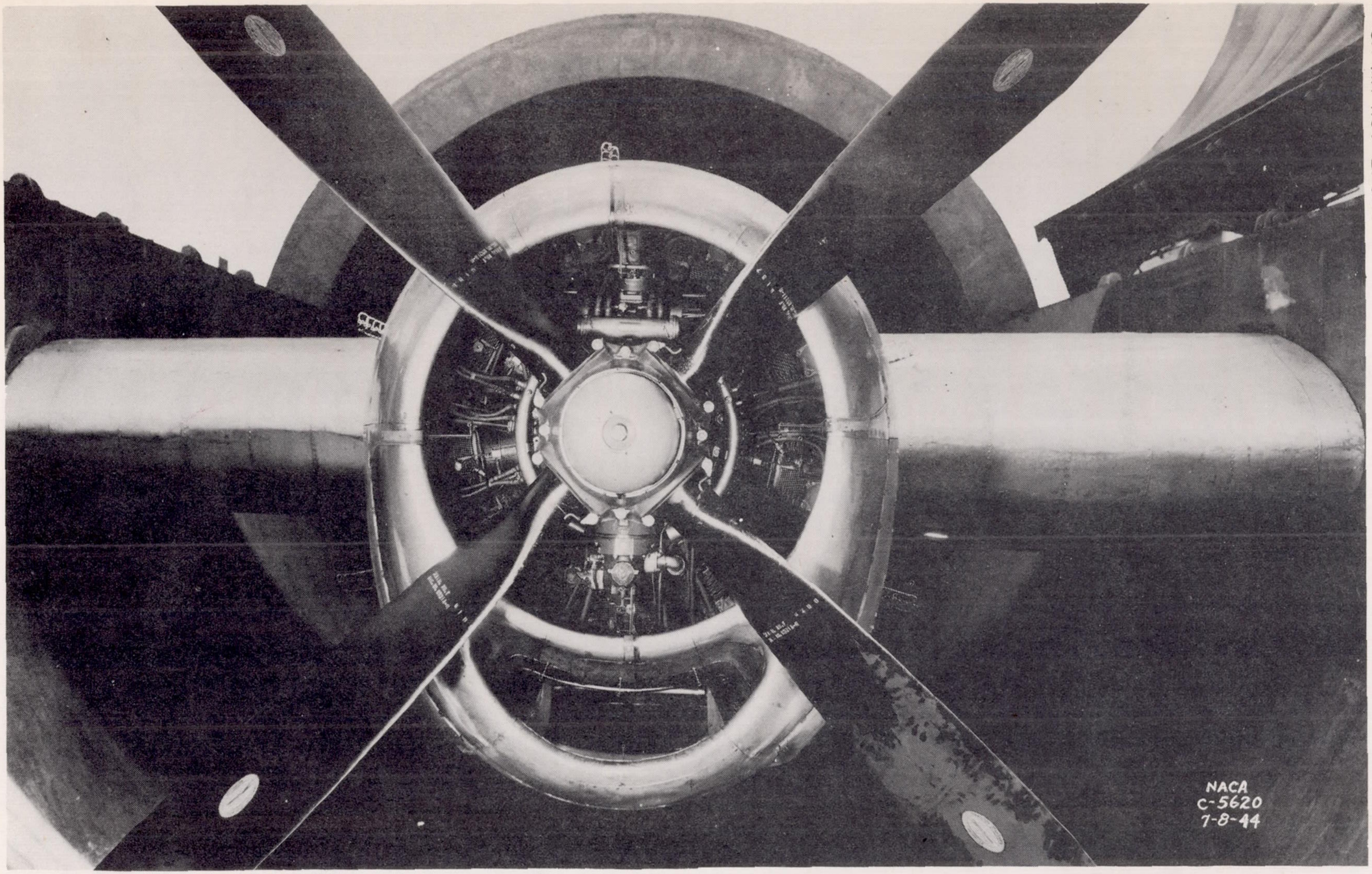
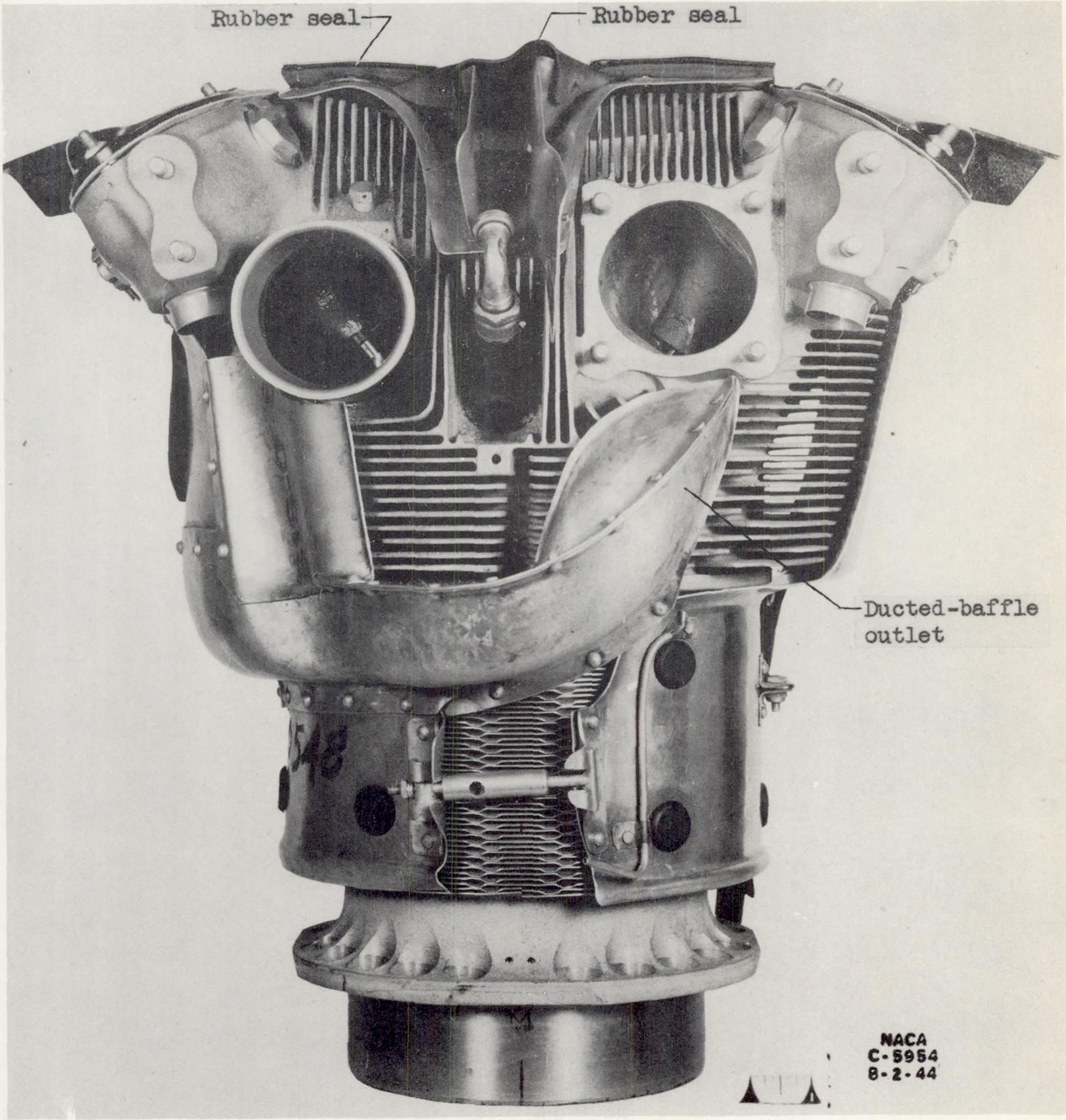
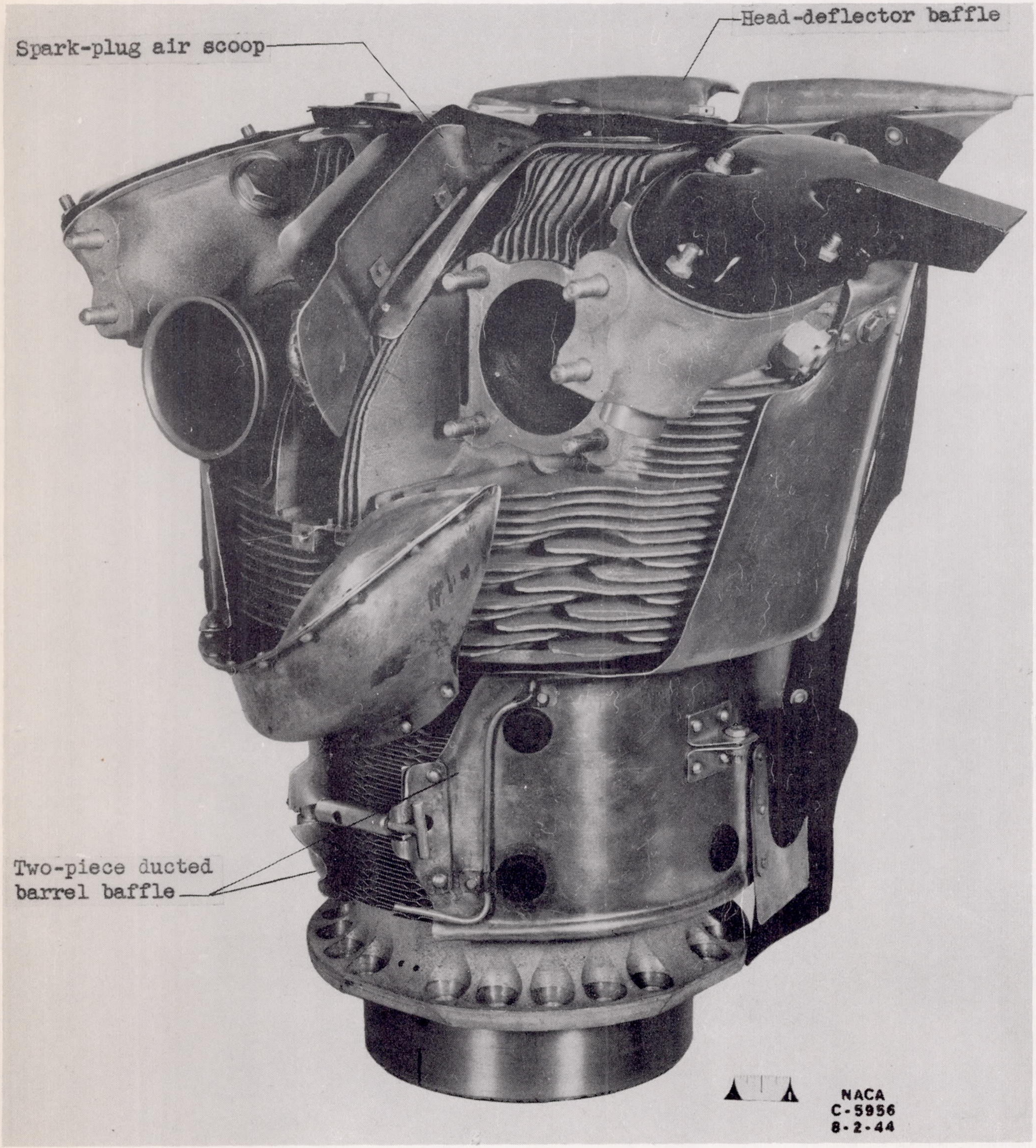


Figure 1. - Front view of bomber power-plant installation in altitude wind tunnel showing 43-inch-diameter cowl inlet without spinner.



(a) Full rear view.

Figure 2. - Modified baffles assembled on double-r w radial engine cylinder.



(b) Rear right-side view.

Figure 2. - Continued.

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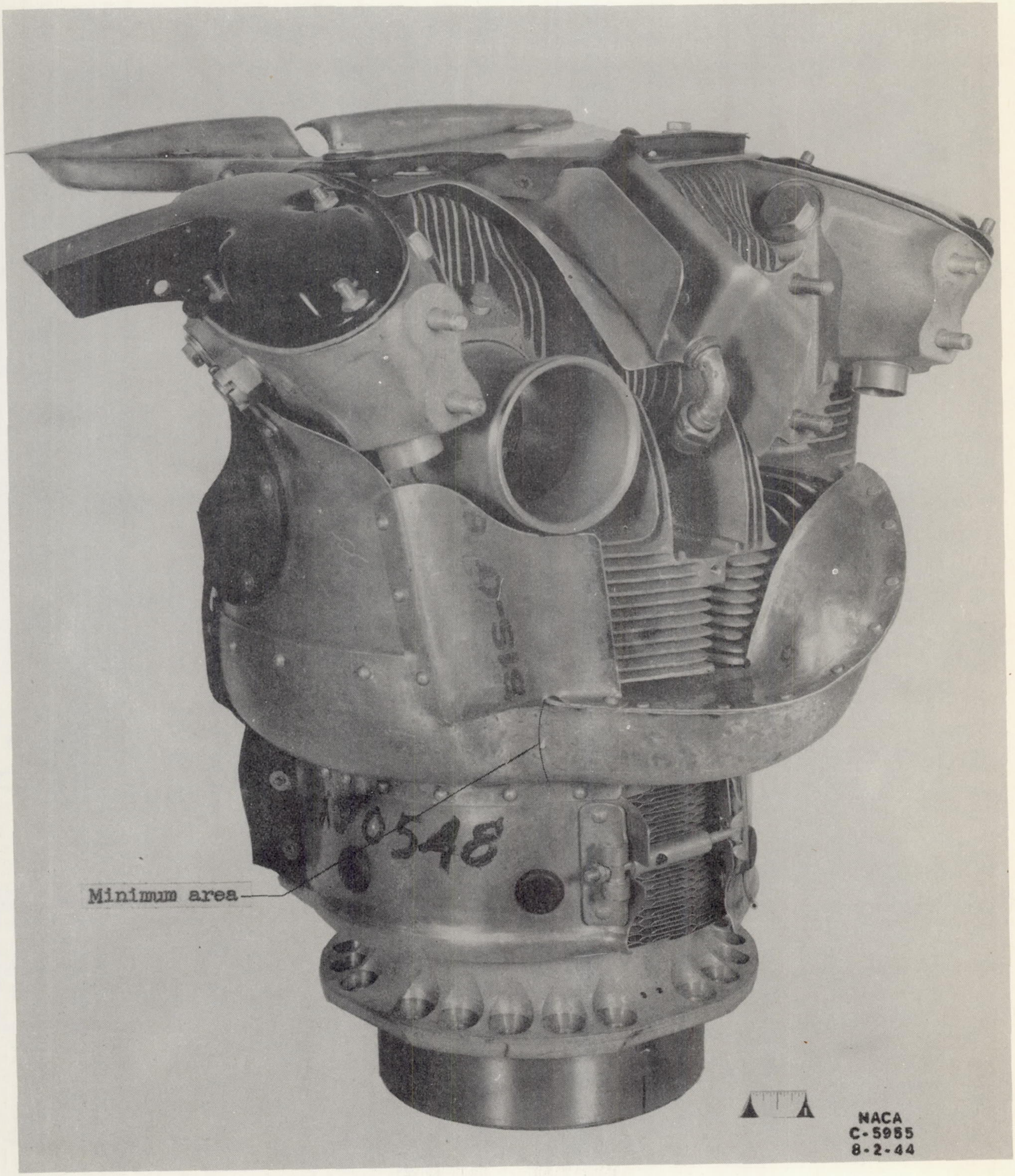
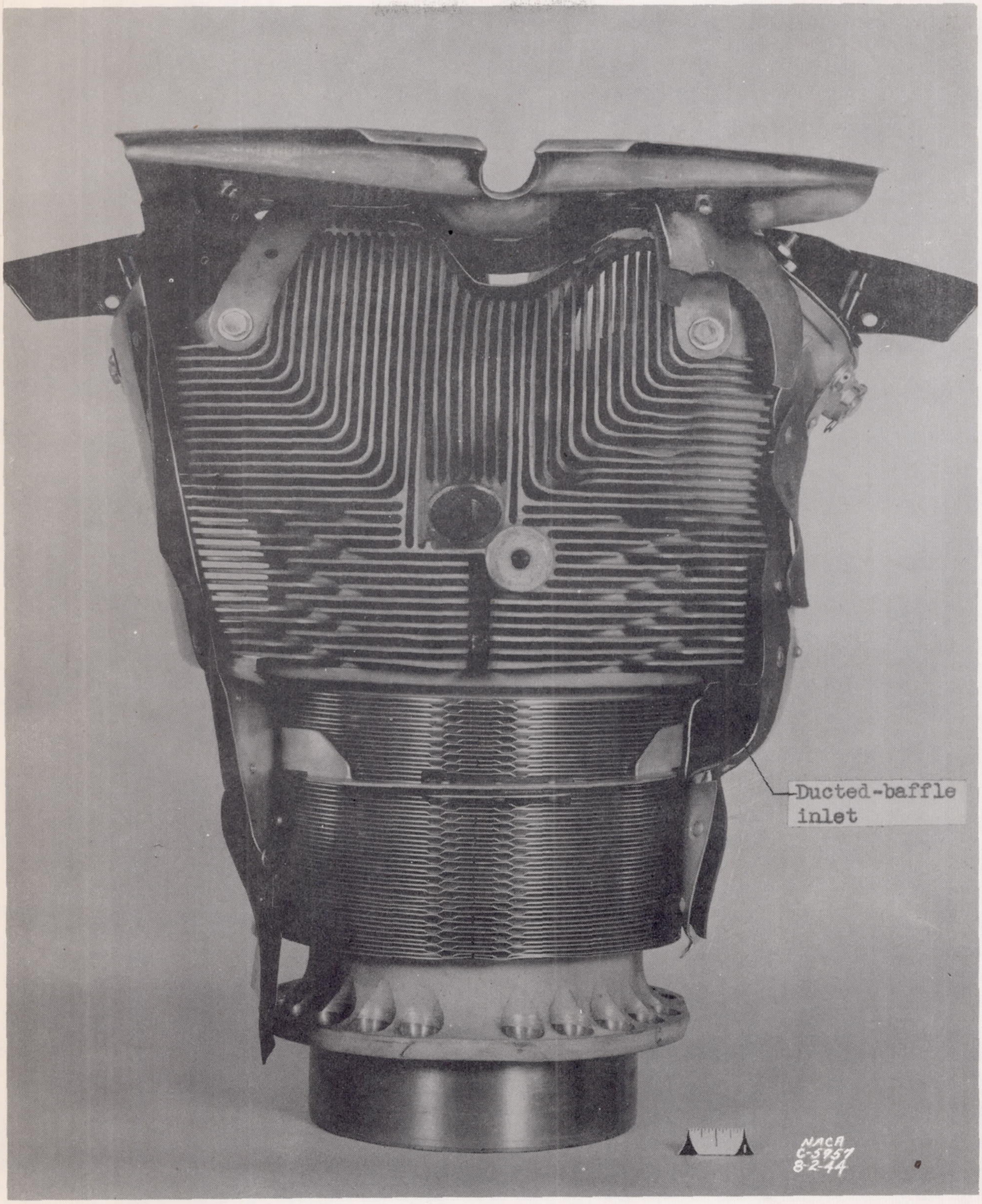


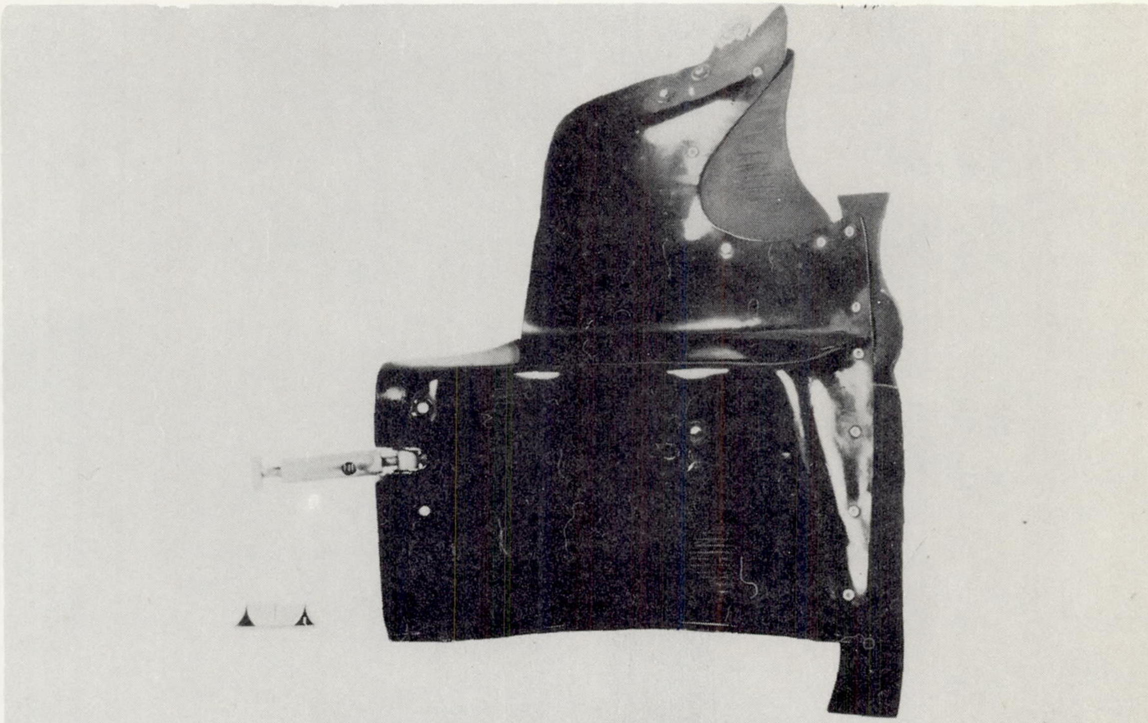
(c) Rear left-side view.

Figure 2. - Continued.

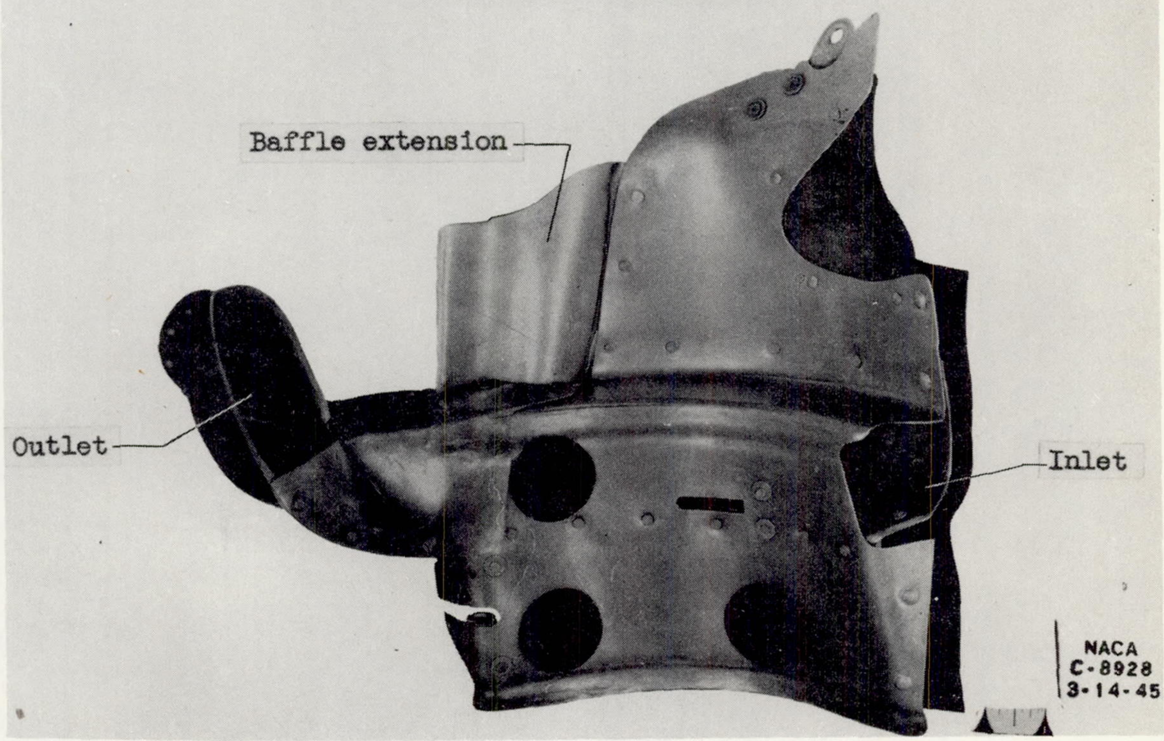


(d) Full front view.

Figure 2. - Concluded.

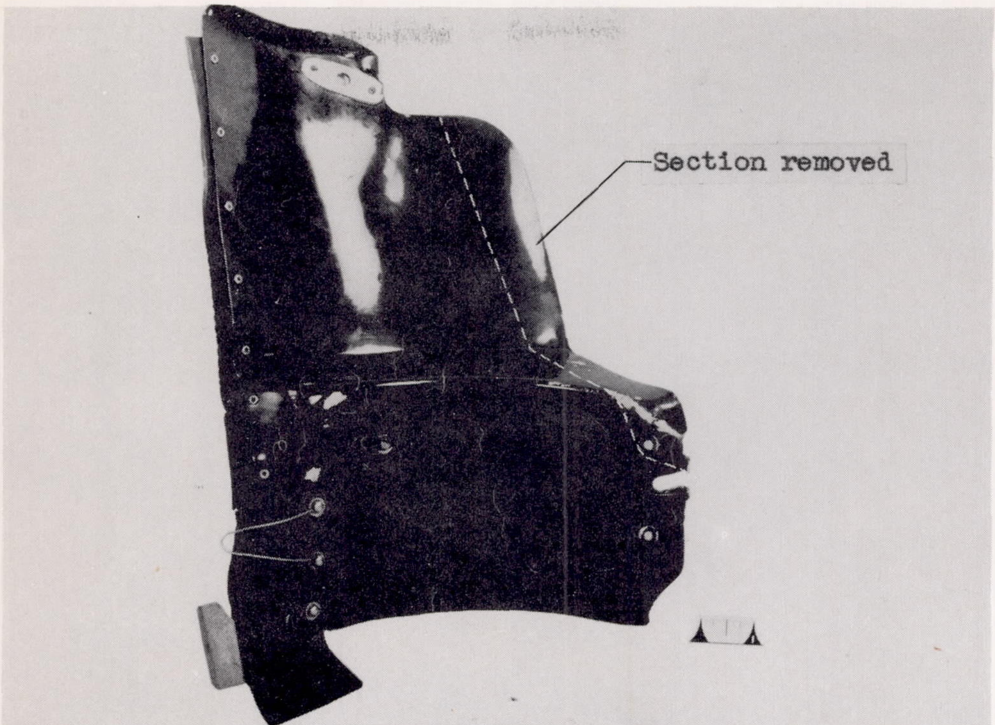


(a) Standard baffle.

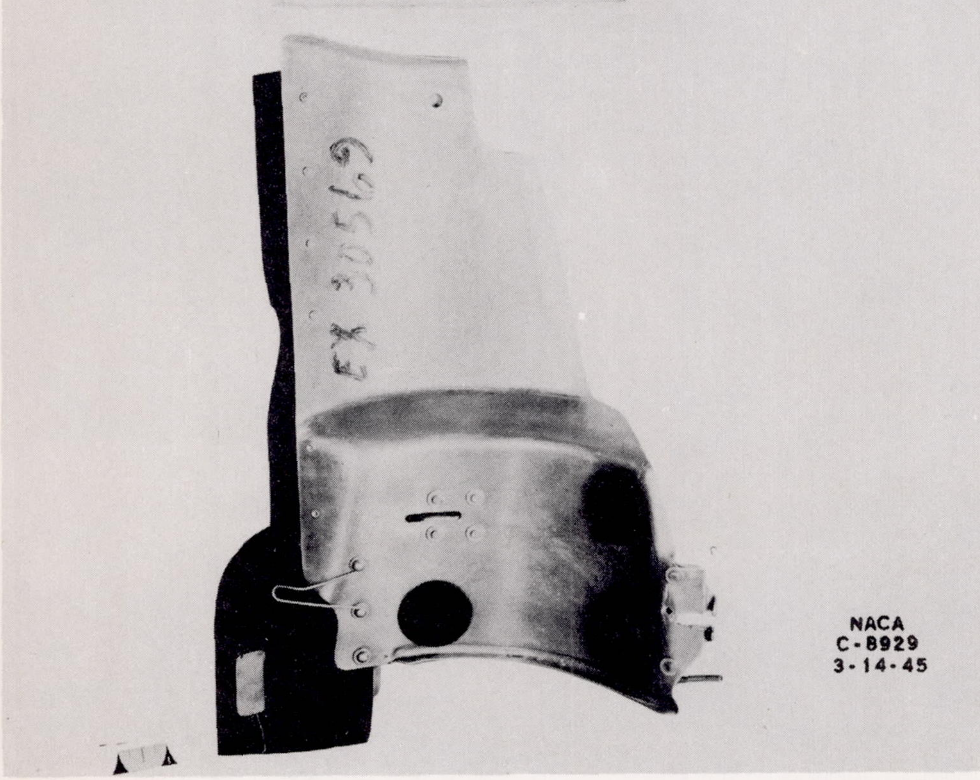


(b) Modified baffle.

Figure 3. - Inside view of left barrel baffle for a rear-row cylinder of double-row radial engine.

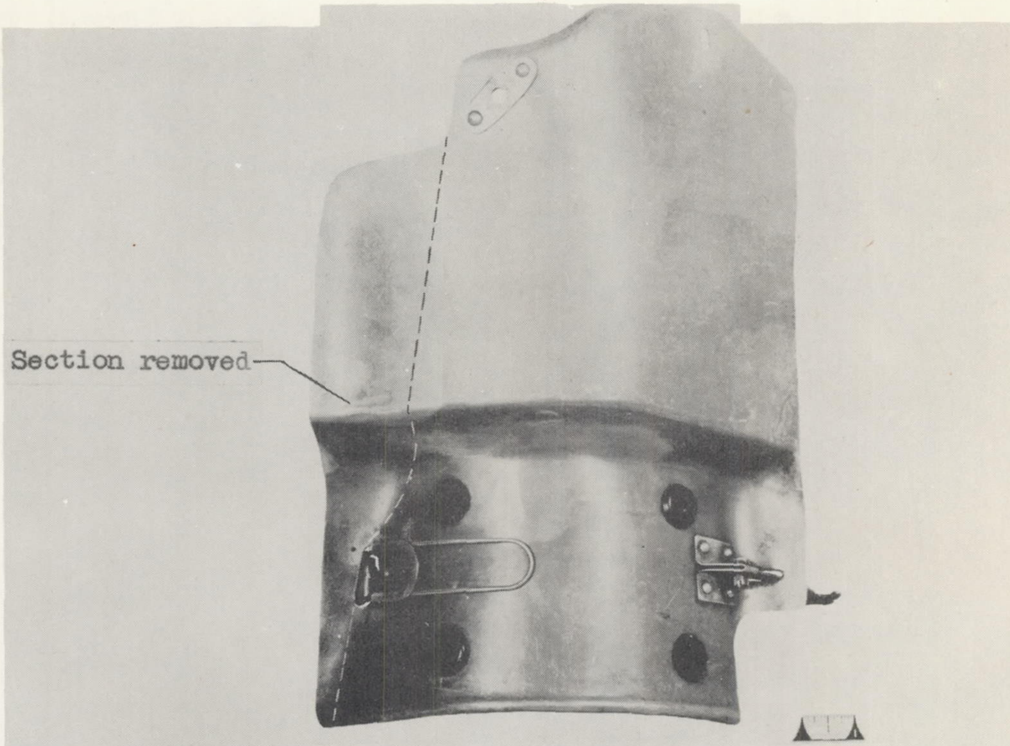


(a) Standard baffle.



(b) Modified baffle.

Figure 4. - Inside view of right barrel baffle for a rear-row cylinder of double-row radial engine.



(a) Standard baffle

(b) Modified baffle.

Figure 5. - Outside view of left barrel baffle for a front-row cylinder of double-row radial engine.

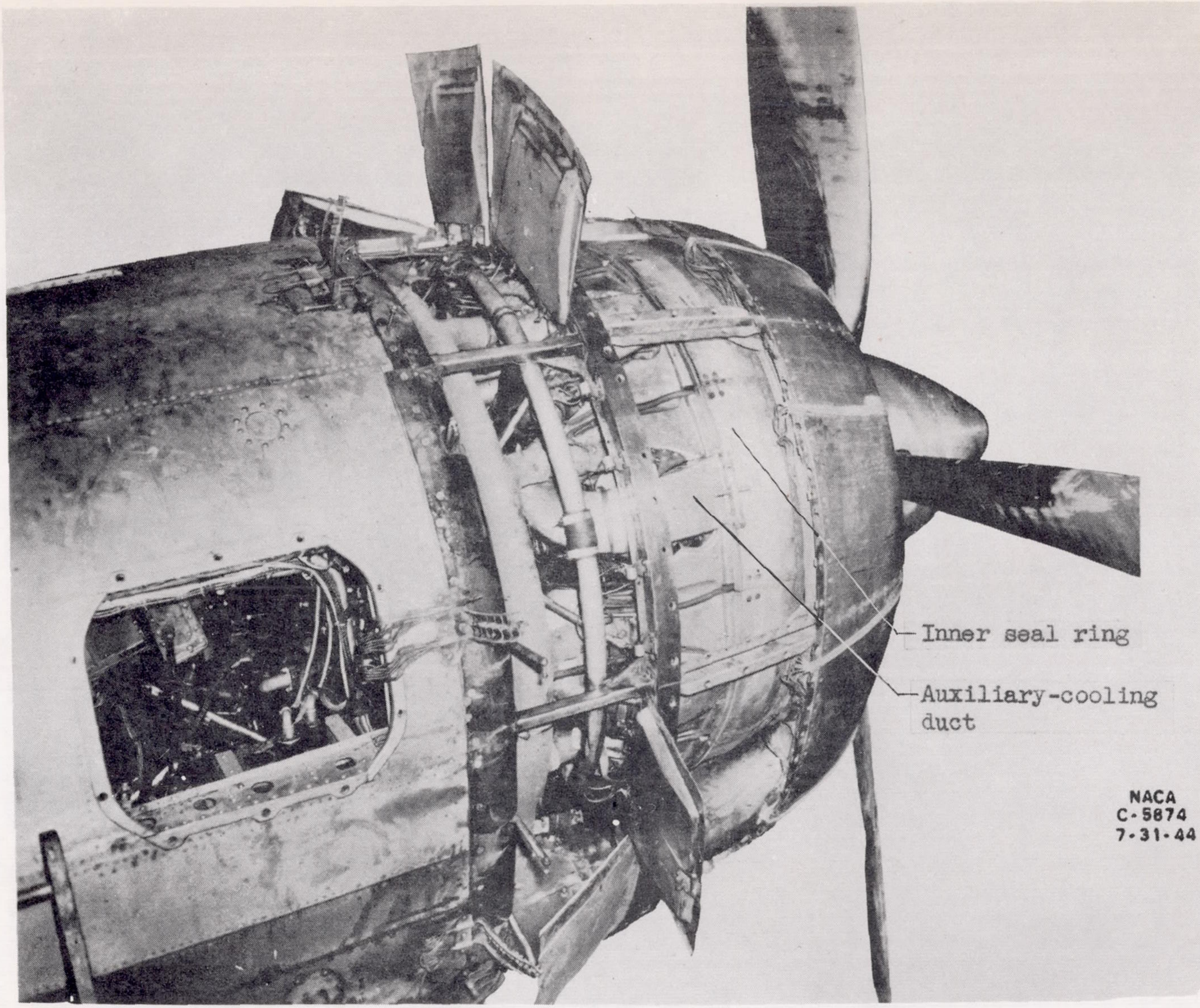
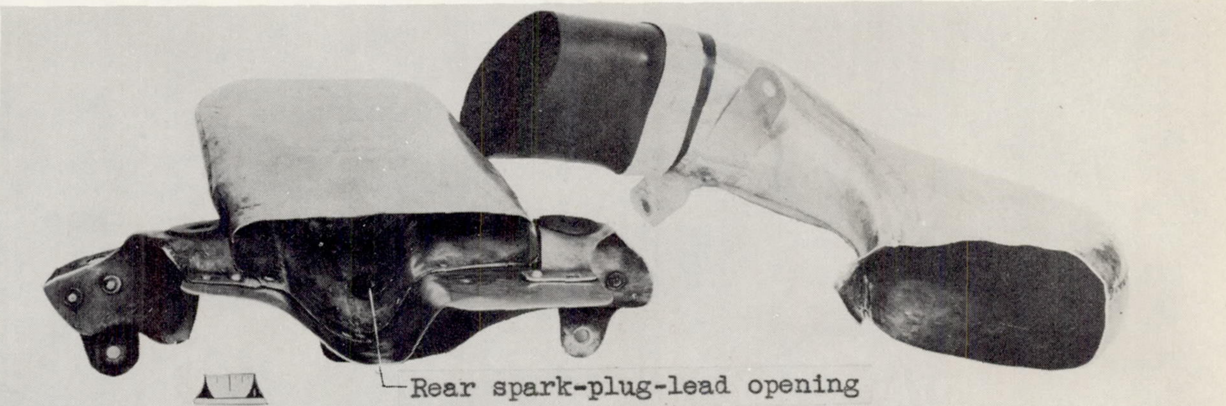
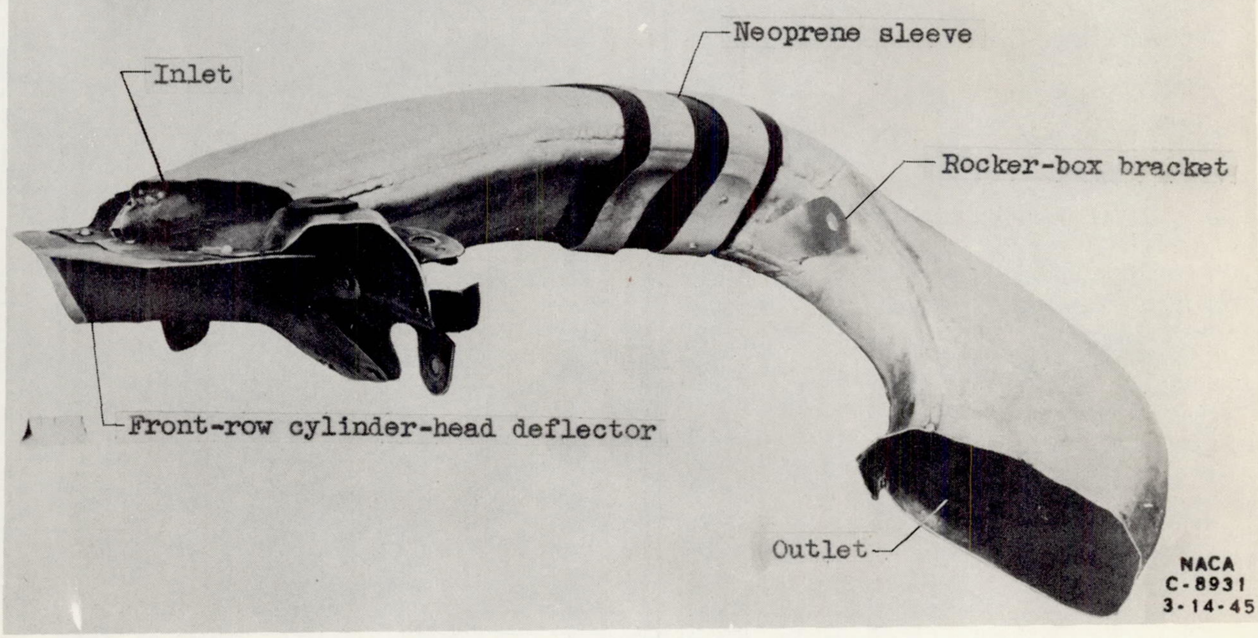


Figure 6. - Auxiliary-cooling duct installed on double-row radial engine.



(a) Sectional view.



(b) Assembled view.

Figure 7. - Auxiliary-cooling duct for double-row radial engine.

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39+254

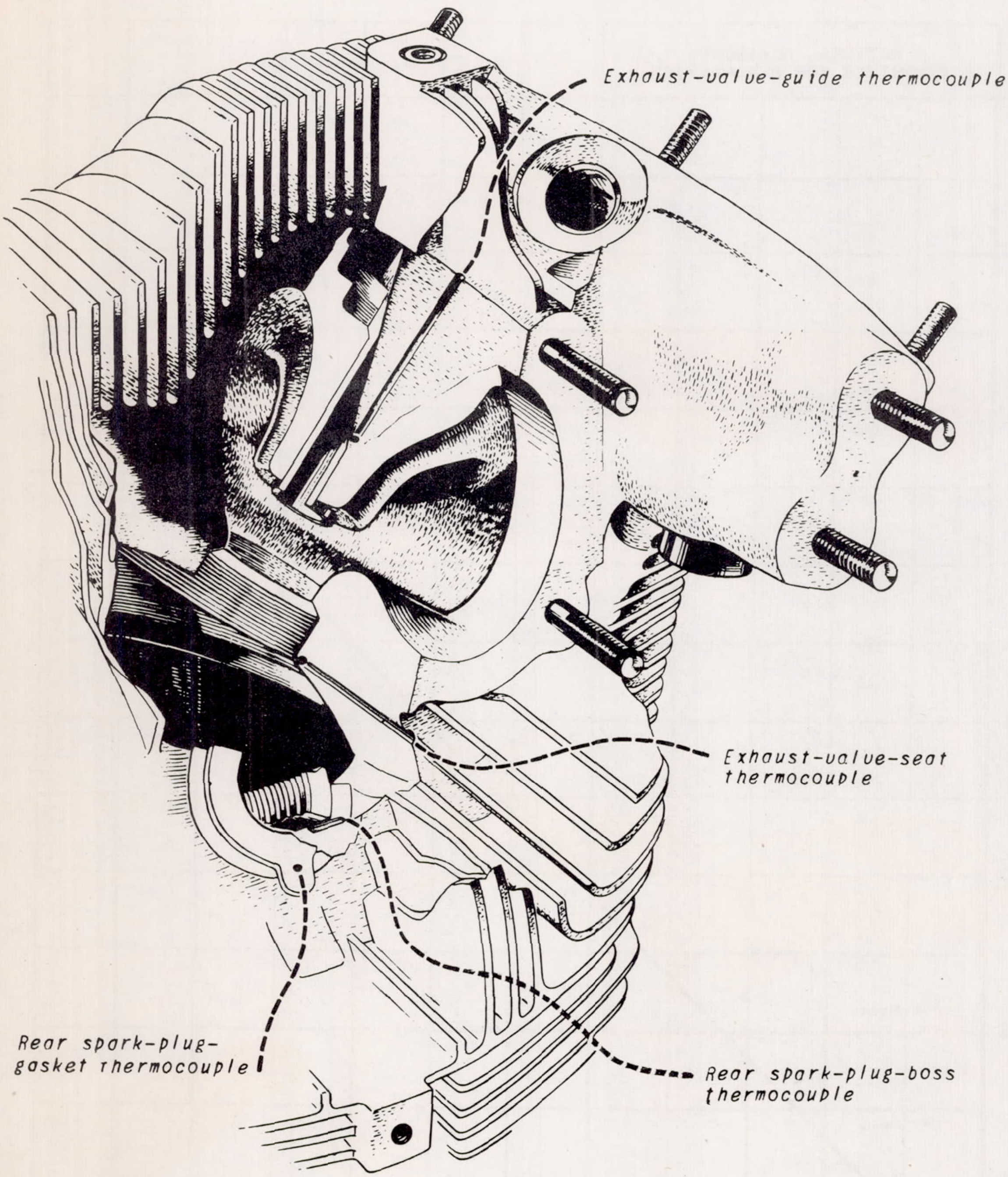

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Figure 8. - Location of cylinder-head thermocouples on double-row radial engine cylinder.

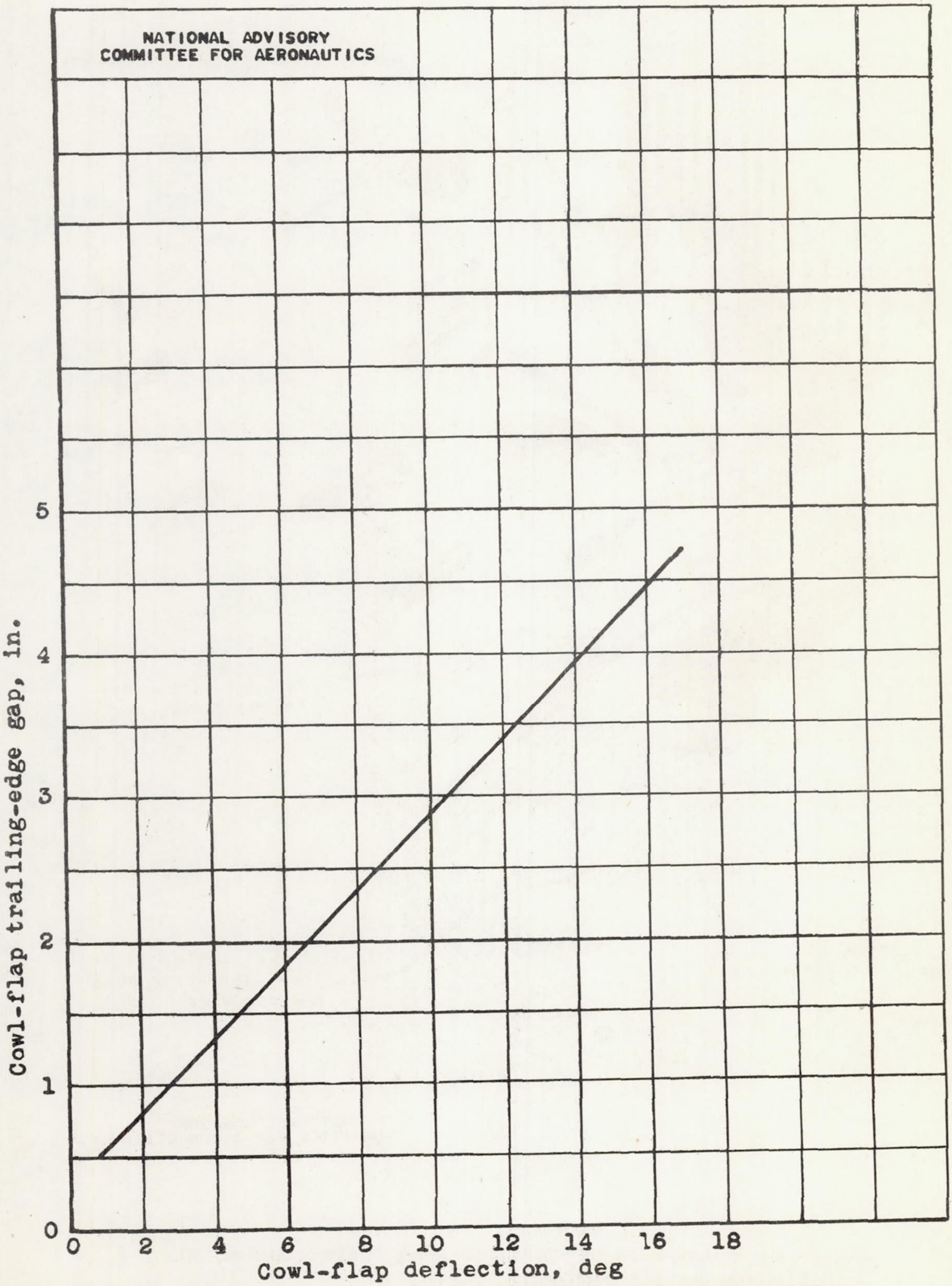
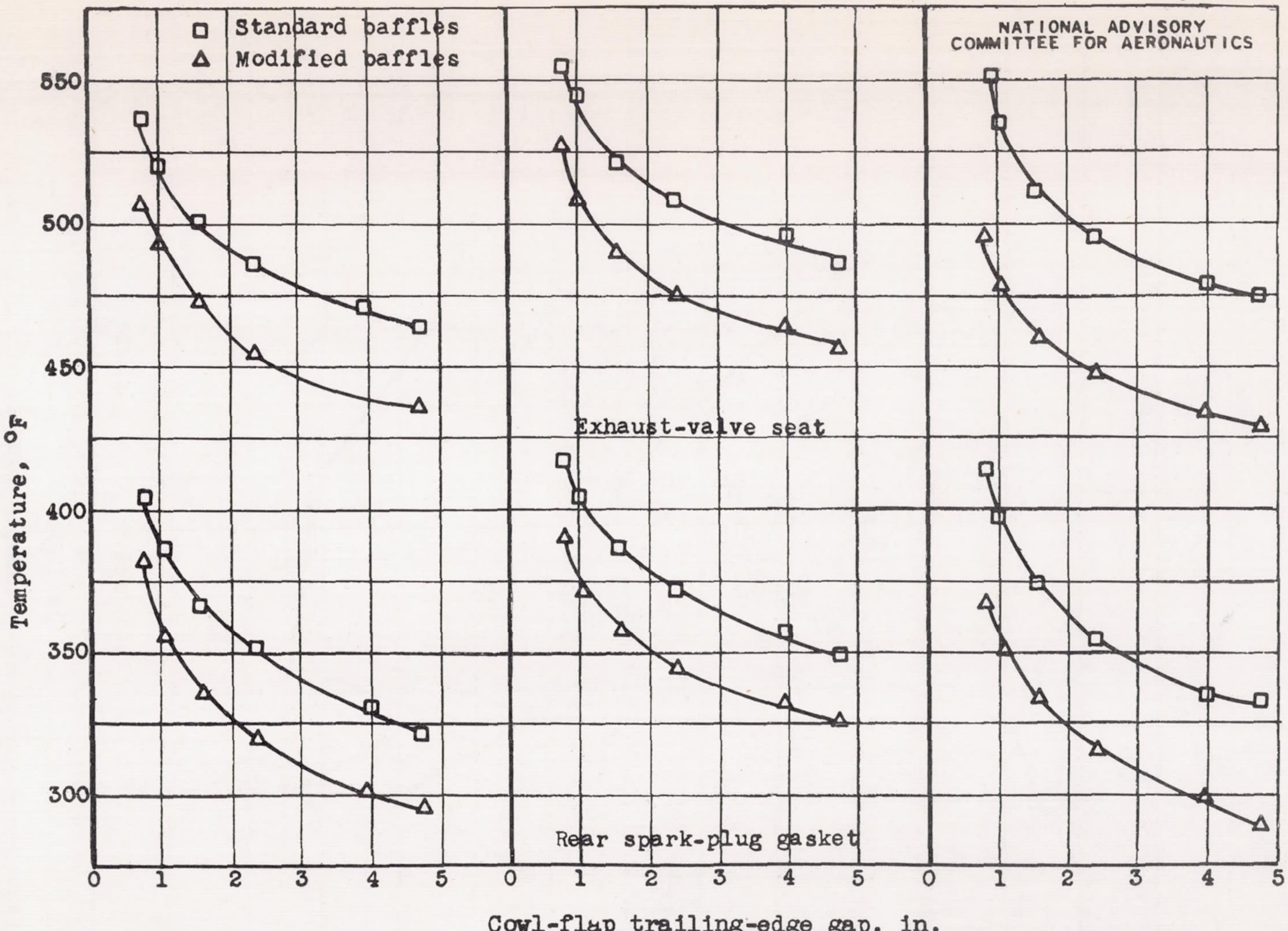


Figure 9.- Relation of cowl-flap deflection to cowl-flap trailing-edge gap for production long cowl flaps.

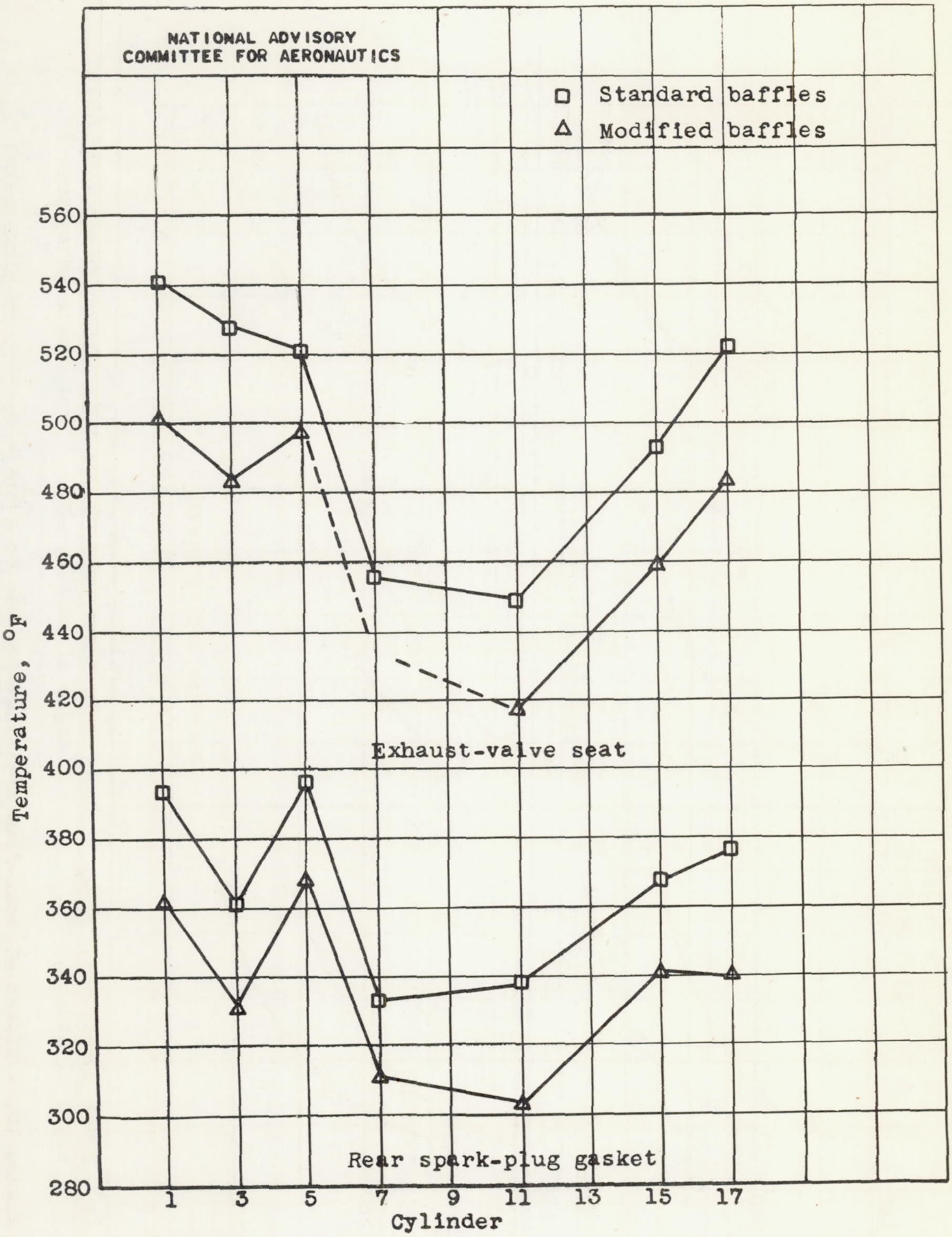


(a) Brake horsepower, 1350; angle of attack, -2°.

(b) Brake horsepower, 2000; angle of attack, -2°.

(c) Brake horsepower, 1350; angle of attack, 1°.

Figure 10. - Effect of cowl-flap trailing-edge gap on average rear-spark-plug-gasket and exhaust-valve-seat temperatures for standard and modified baffles. Double-row radial engine.



(a) Brake horsepower, 1350; engine speed, 2100 rpm; angle of attack, -2°; cowl-flap trailing-edge gap, 1.58 inches.

Figure 11. - Rear-spark-plug-gasket and exhaust-valve-seat temperature patterns for standard and modified baffles. Double-row radial engine.

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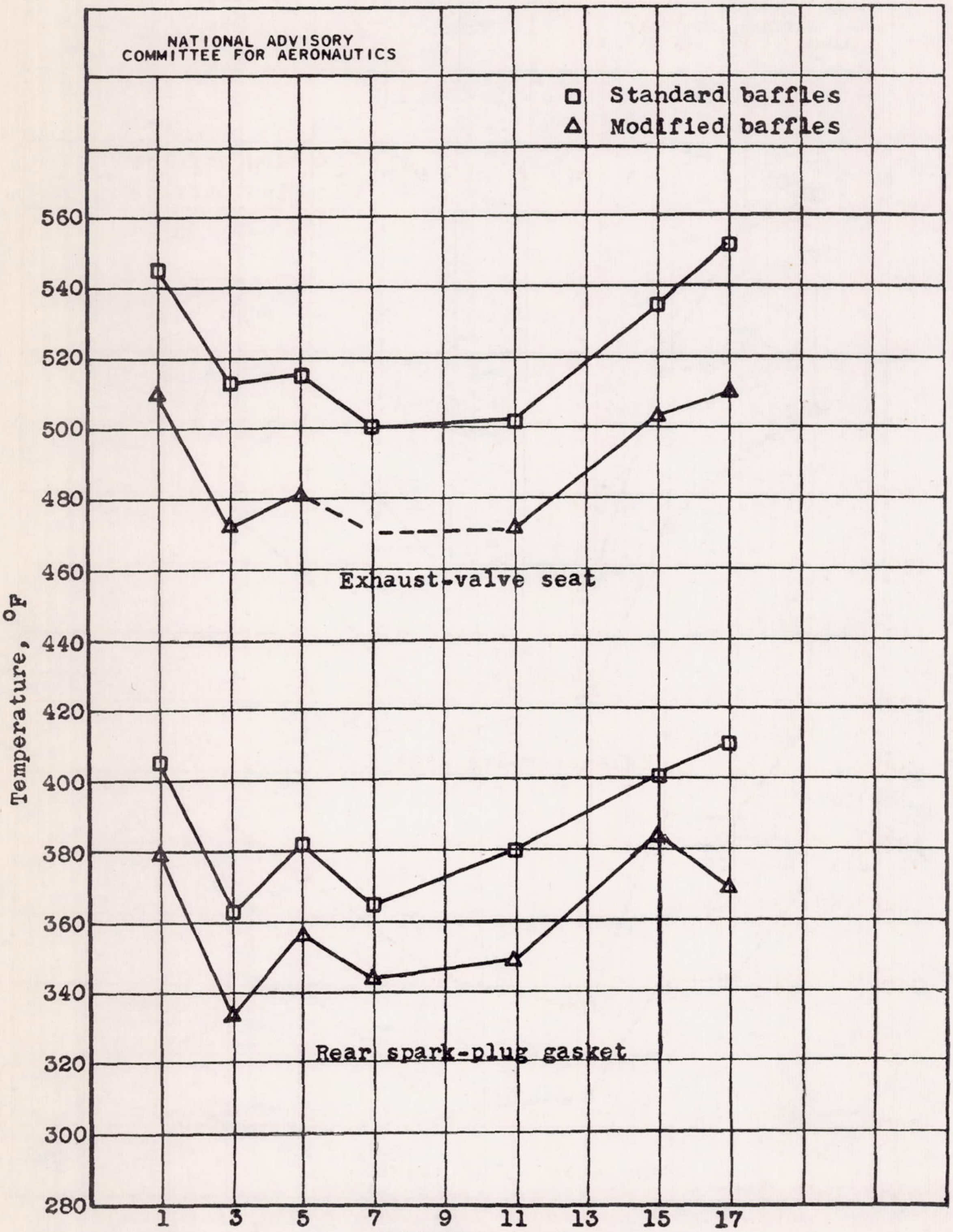
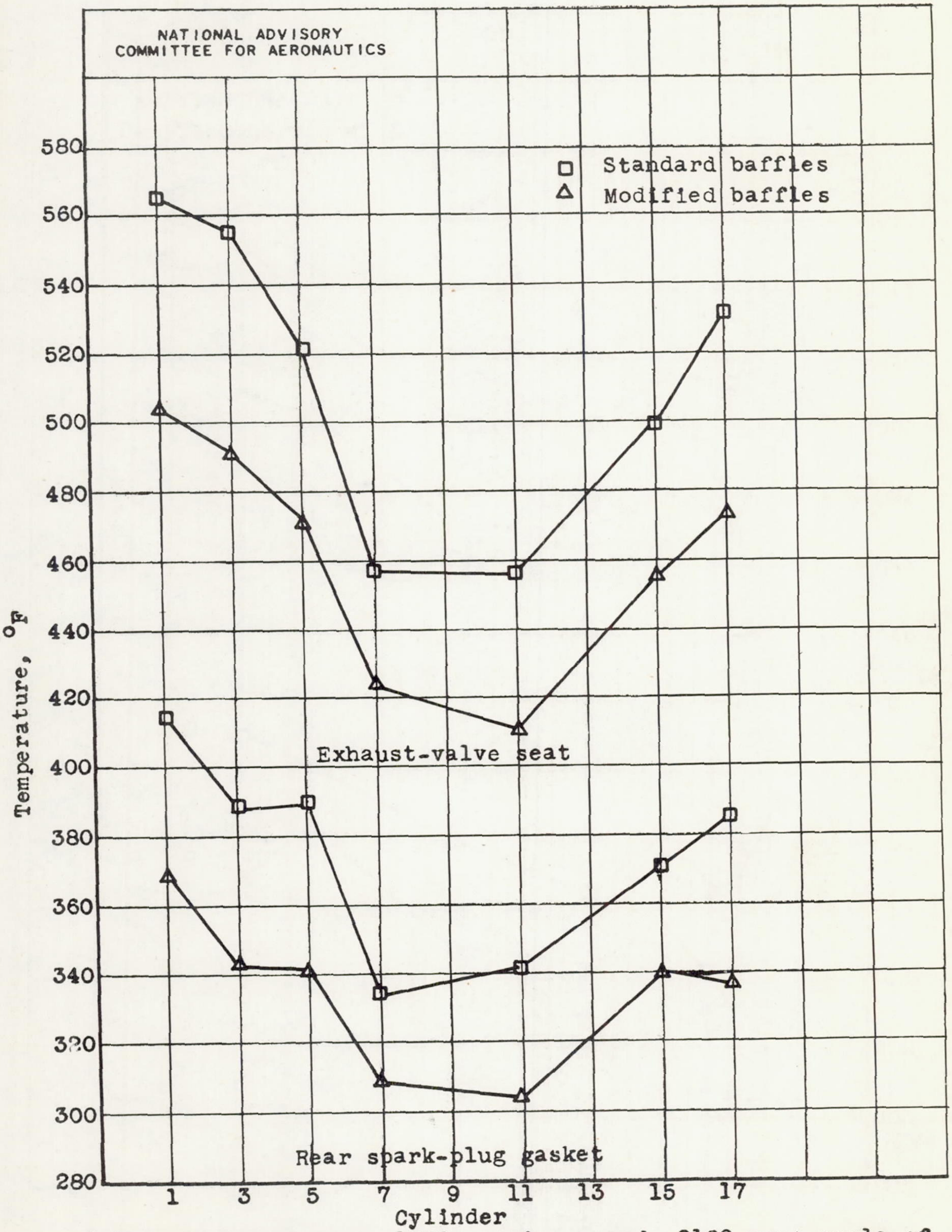


(b) Brake horsepower, 2000; engine speed, 2400 rpm; angle of attack, -2°; cowl-flap trailing-edge gap, 1.58 inches.

Figure 11.- Continued.



(c) Brake horsepower, 1350; engine speed, 2100 rpm; angle of attack, 1°; cowl-flap trailing-edge gap, 1.53 inches.

Figure 11.- Concluded.

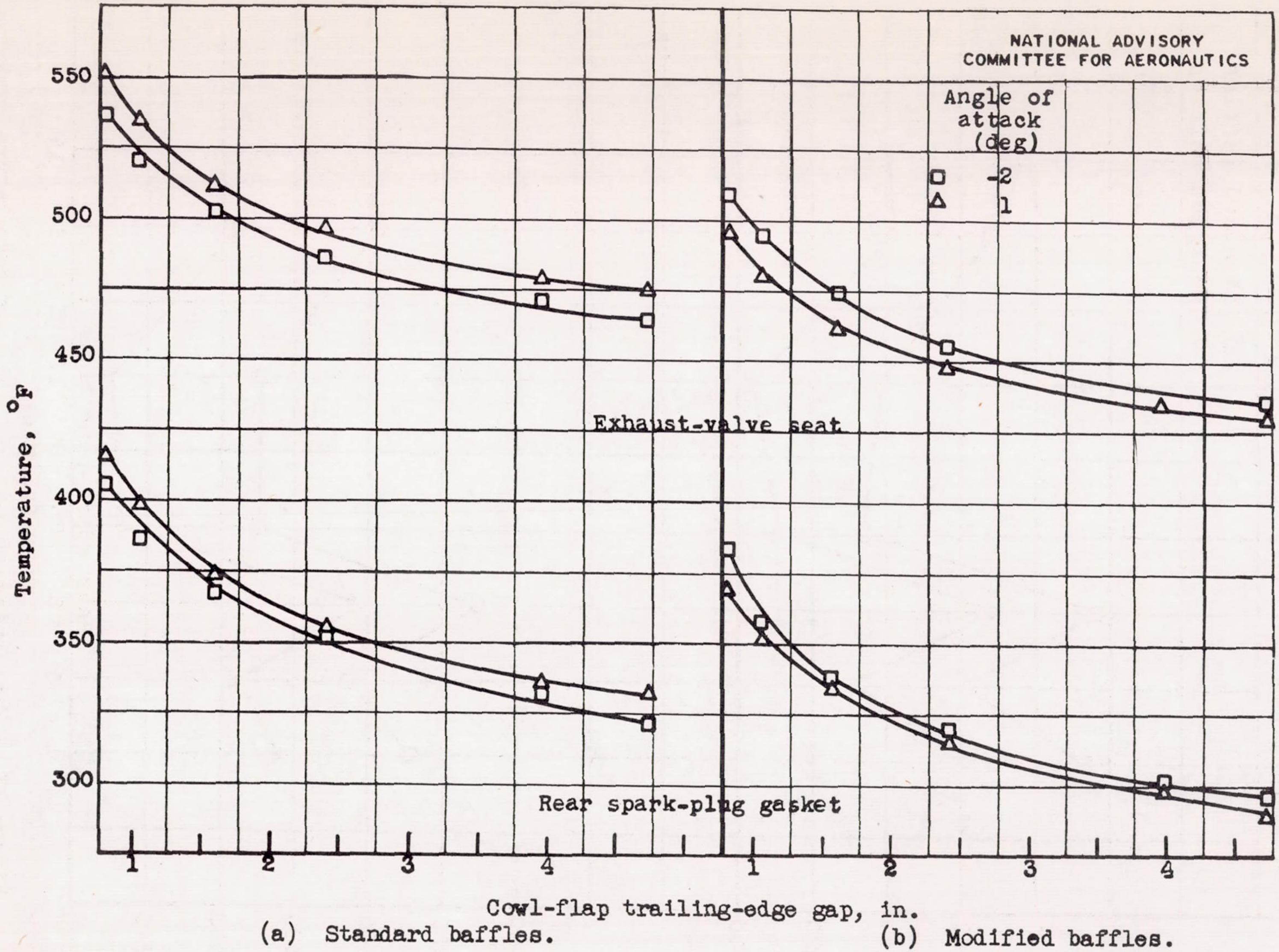


Figure 12. - Effect of cowl-flap trailing-edge gap on average rear-spark-plug-gasket and exhaust-valve-seat temperatures at -2° and 1° angles of attack for standard and modified baffles. Brake horsepower, 1350. Double-row radial engine.

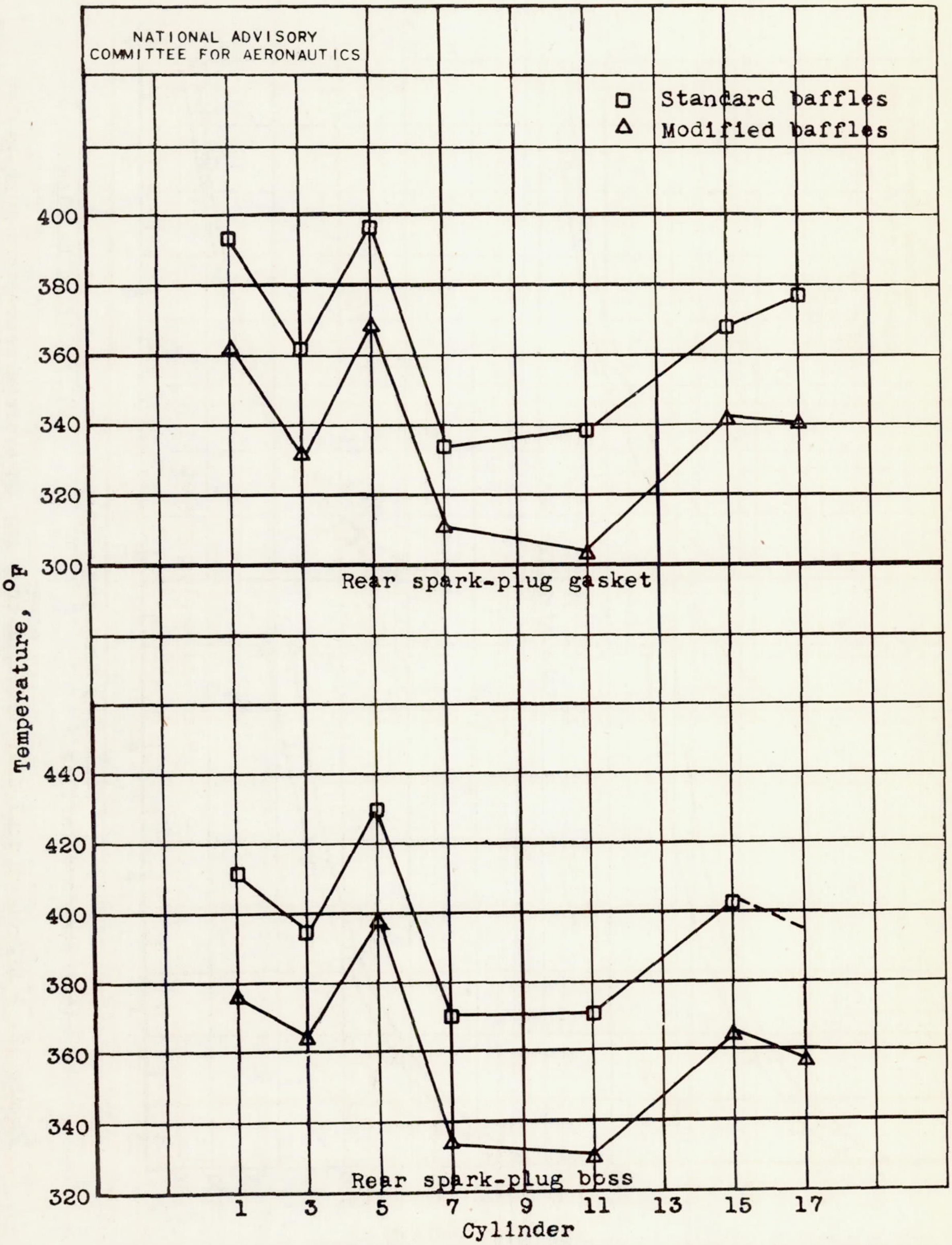


Figure 13. - Rear-spark-plug-gasket and boss temperature patterns for standard and modified baffles. Brake horsepower, 1350; engine speed, 2100 rpm; angle of attack, -2°; cowl-flap trailing-edge gap, 1.58 inches. Double-row radial engine.

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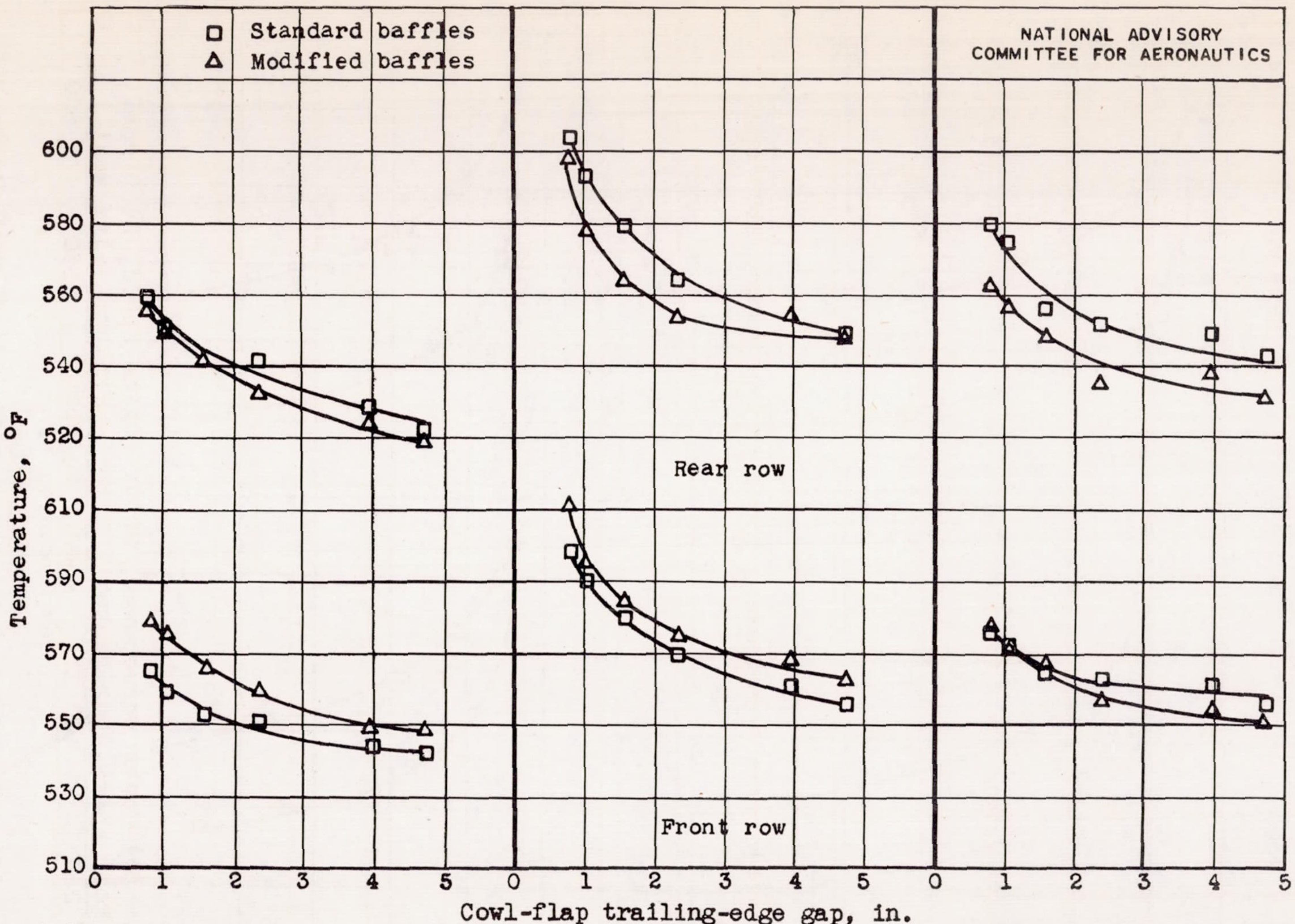

(a) Brake horsepower, 1350; angle of attack, -2°.
(b) Brake horsepower, 2000; angle of attack, -2°.
(c) Brake horsepower, 1350; angle of attack, 1°.

Figure 14. - Effect of cowl-flap trailing-edge gap on the average rear-row and front-row exhaust-valve-guide temperatures for standard and modified baffles. Double-row radial engine.

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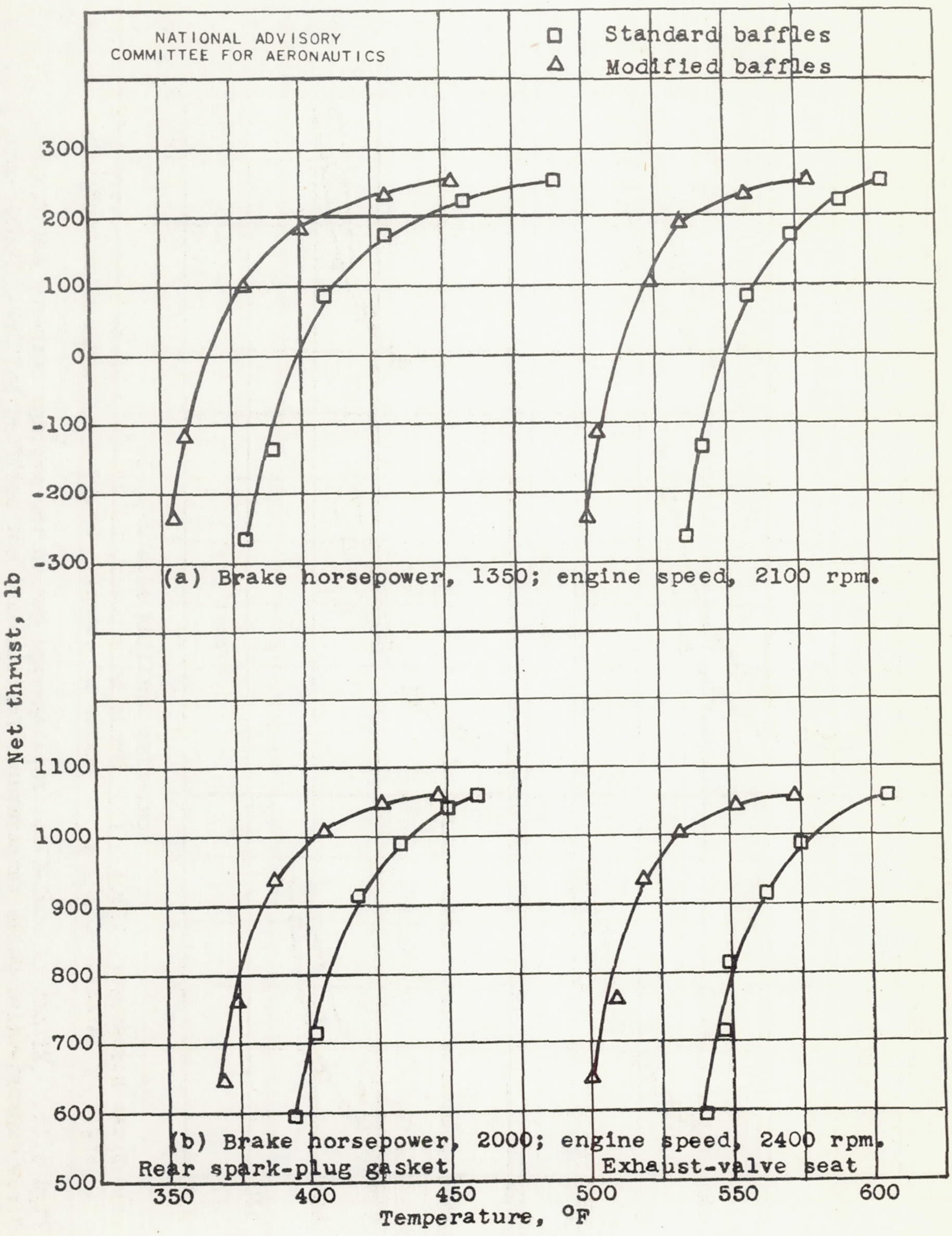

Figure 15. - Variation of net thrust with hottest rear-spark-plug-gasket and exhaust-valve-seat temperatures for standard and modified baffles. Variable trailing-edge gap; angle of attack, -2°; indicated airspeed, 190 miles per hour; pressure altitude, 15,000 feet. Double-row radial engine in bomber power-plant installation.

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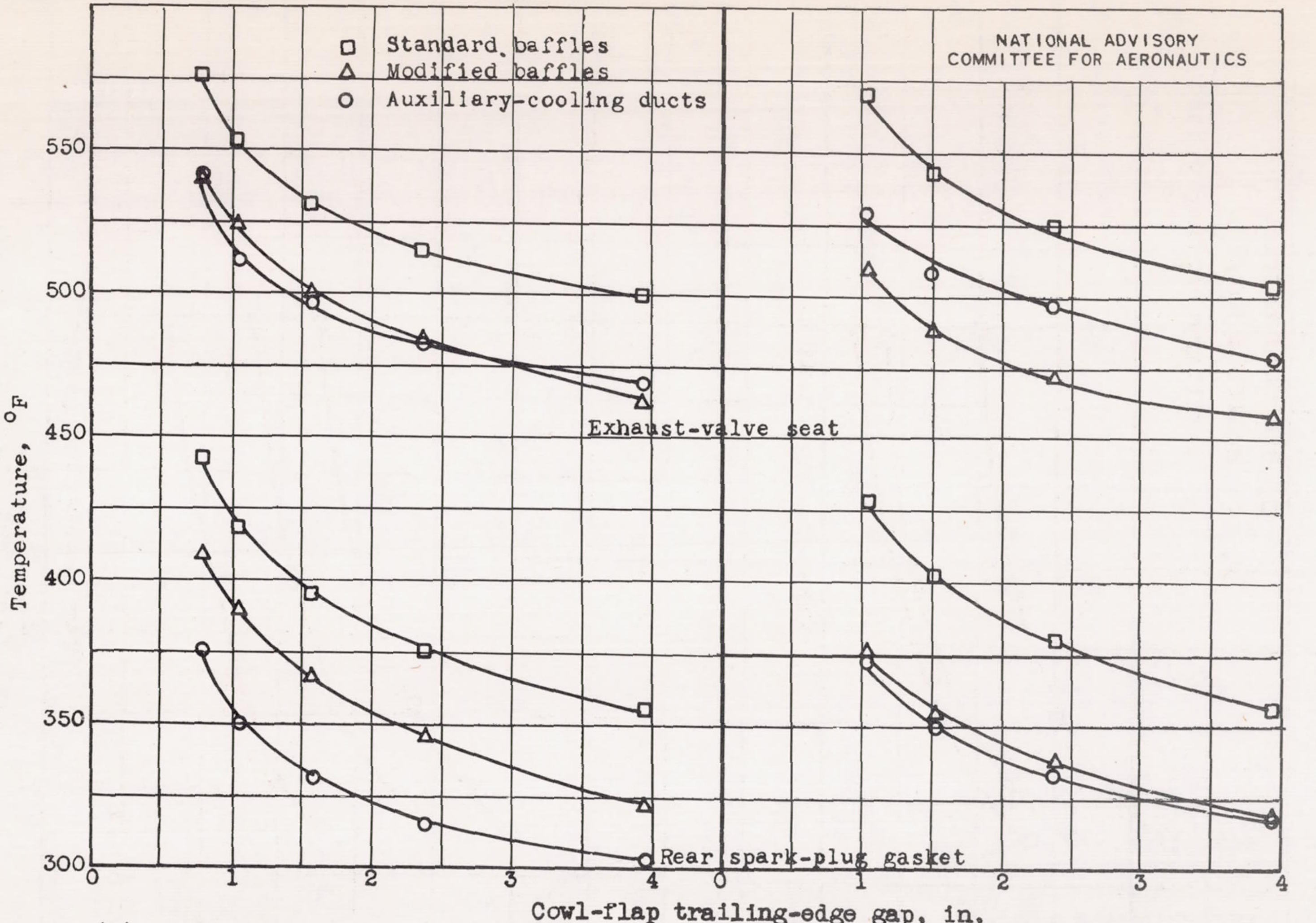
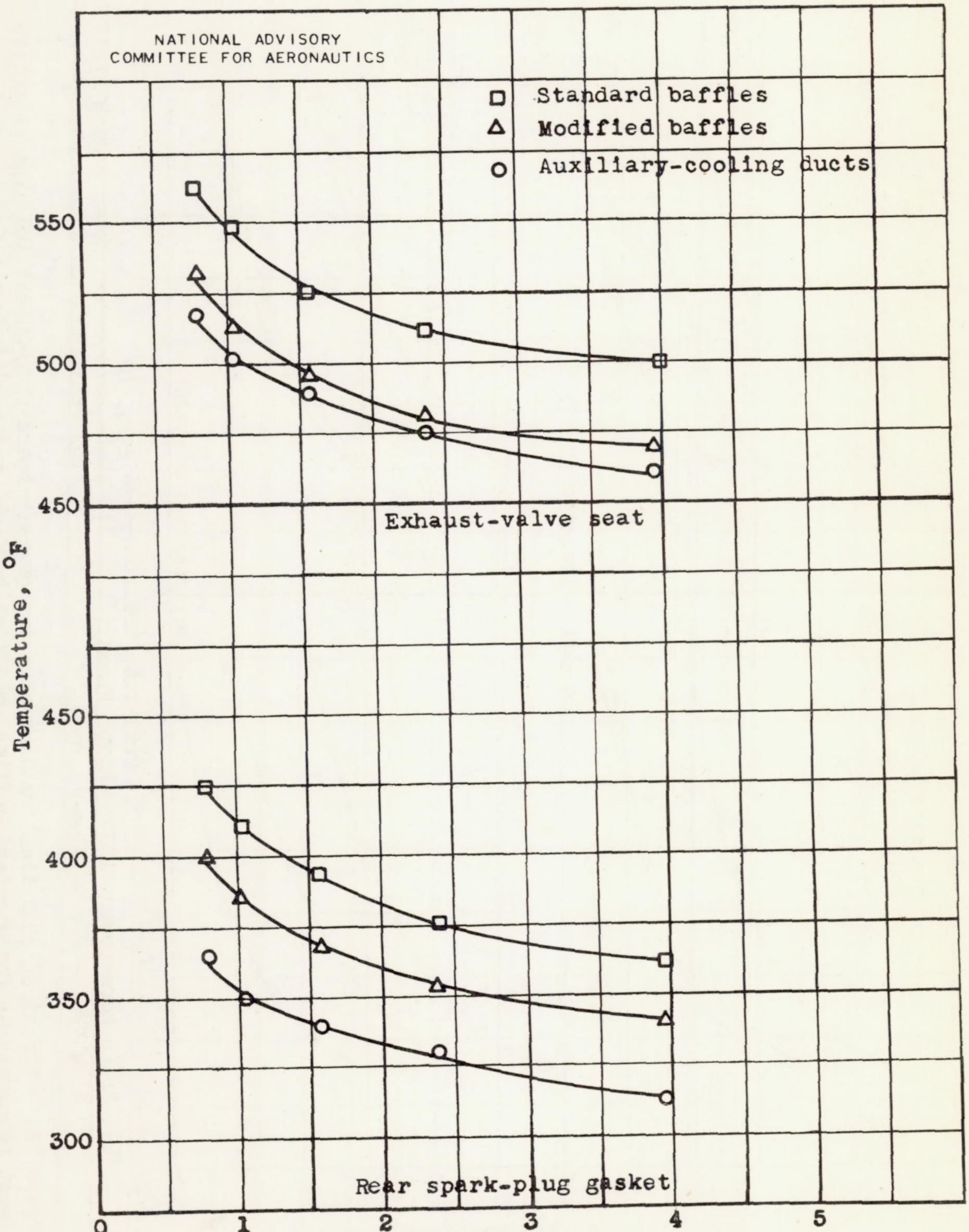


(a) Brake horsepower, 1350; engine speed, 2100 rpm; angle of attack, -2°.

(b) Brake horsepower, 1350; engine speed; 2100 rpm; angle of attack, 1°.

Figure 16. - Effect of cowl-flap trailing-edge gap on rear-spark-plug-gasket and exhaust-valve-seat temperatures for standard baffles, modified baffles, and auxiliary-cooling ducts. Double-row radial engine.



(c) Brake horsepower, 2000; engine speed, 2400 rpm; angle of attack, -2°.

Figure 16.- Concluded.